A REVIEW OF SELECTED U.S. GOVERNMENT RESEARCH AND DEVELOPMENT REPORTS OTR-119

HONEYCOMB and SANDWICH MATERIALS

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This study is one of a series of reviews of selected Government research and development reports. It highlights significant technical information for the attention of the industrial community. These reports may offer ideas for materials and product development and/or means of reducing production costs.

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HONEYCOMB AND SANDWICH MATERIALS

ABSTRACT

Significant reports covering the period since 1962 were selected for this study, with reference to relevant earlier works. Recent research in honeycomb sandwich structural materials concerns: (1) the investigation of manufacturing methods and design; (2) testing of panels of various constructions for the effects of elevated temperatures, edgewise compression, thermal response, energy absorption, vibration, and strength as affected by surface waviness and core cell size; (3) testing the joining (welding and brazing) properties of various alloys.

Key words: **cores, honeycomb, laminates, sandwich.**

REVIEW OF RESEARCH REPORTS

Introduction

Government-sponsored studies over the past several years have added considerably to the data previously compiled on the manufacturing methods, design, and the characteristics of materials being used in honeycomb sandwich panels. The reports cover a wide range of uses, from building construction, through the development and evaluation of a lightweight aluminum honeycomb case, to the design of molybdenum and columbium panels used for heat shields and structural applications on aerospace vehicles.

Materials Design & Development

The Agriculture Department's Forest Products Laboratory has maintained a long-time interest in sandwich materials, especially those utilizing wood products as the basic material. Report AD–600 869P describes the experimental unit whereby various types of sandwich wall panels suitable for use in dwellings were given longtime exposure to the elements. In a project reported in Jan. 64, AD–432 259D, the Forest Products Laboratory determined the effect of honeycomb core cell size on edgewise compression of sandwich constructions. Sandwich specimens were evaluated that had aluminum facings of various thicknesses and cores of Sitka spruce. In some cases this wood core was found to be superior to aluminum honeycomb specimens.

The Forest Products Laboratory developed, as a result of this effort, an empirical formula for estimating critical stresses at which failures occur in honeycomb structures.

The Laboratory's interest in sandwich cores has also extended to corrugated cores that were fabricated from 0.002-inch thick foil of 5052–H39 aluminum. These materials, reported in AD–293 413P, were found to have high strength-to-weight ratios suitable for airborne applications.

Extensive work in the "Mechanical Properties of Several Honeycomb Cores" is described by the Forest Products Laboratory in AD–291 995P. Experimental cores of heat-resistant reinforced plastic and several commercial and developmental aluminum cores were considered in this design effort. The project found that in analyzing and comparing the results of the mechanical properties with the empirical formulas, the performance of aluminum honeycomb cores can be approximately predicted if core density is known.

The Boeing Company operating under Air Force sponsorship has been conducting materials research in the ceramics field. In AD–282 903P "Ceramic Dielectric Sandwich Components" were studied to determine the feasibility of fabricating ceramic materials for radar radome use. The goal here was to achieve high strength-to-weight ratio qualities with a resistance to extreme environments. A slip casting of 97% Al_2O_3 was chosen as an optimum material. The Boeing Company has also developed thoria and magnesia bodies for use in metal ceramic composites. Exotic materials like platinum and Inconel honeycomb were found suitable for metal reinforcement use.

While the Air Force has sponsored the bulk of the Government research in sandwich materials, the Navy Department has sponsored a program at the Penn State Ordnance Research Laboratory on "Shells For Underwater Vehicles." This program has outlined the basic shell designs currently available and the materials suitable for their development. The program surveyed ring-stiffened shells, sandwich shells, and the internal pressurization of sandwich shell designs, making at the same time some evaluations of shell designs that represent the current state-of-the-art in this field (AD–285 862P).

In Air Force programs, the Flight Dynamics Laboratory has accomplished a system of equations for predicting the thermal responses in a variety of sandwich panels. The analytical model developed considers a variety of configurations involving single or stacked panels of square or hexagonal core cells. The three basic modes of heat transfer are considered as well as the temperature dependent thermophysical properties of the materials used in fabricating the panels. This effort is interesting in that the system of equations has been programmed for computer solution (IBM 7094). The work reported in AD–607 088P gives evidence of the model's validity by comparing predicted results with experimental data for single honeycomb panels.

Another report in this analytical vein, also under Air Force contract, determines the "Energy Absorption Characteristics of Various Low Density Foam Type Plastics" (AD–431 513P).

And of note is an Army Quartermaster Research and Engineering Command report describing the development of a "Cold Water-Soluble Honeycomb Facing Adhesive" accomplished by Arthur D. Little Company. An amylopectin starch was found to be the most satisfactory dry-facing adhesive. This work was done because of the U.S. Army's desire to develop a cushioning material for air-drop operations. Expanded paper honeycomb, faced on both sides with kraft paper, is the presently accepted cushioning material because the honeycomb possesses high strength-to-weight properties and has excellent energy absorption properties. The kraft paper facing, when bonded to the expanded honeycomb, serves the dual purposes of keeping the honeycomb expanded as well as trapping air in the structure, thereby improving

the impact-cushioning properties. This concept of storing and handling collapsed paper honeycomb for field assembly may have many developing alternate uses (AD–286 490P).

Manufacturing & Joining Methods

The advent of supersonic vehicles has resulted in the requirement for structures to operate at 600° to 800°F. In that regard the Air Force has sponsored a "Manufacturing Methods for Brazed Refractory Metal Honeycomb Sandwich Panels" program. Brazed titanium and stainless steel honeycomb have been developed to meet high temperature requirements. This general field of refractory metals technology has received much attention because of the advent of hypersonic vehicles. Report AD–417 415P describes efforts to develop a complete technology for brazed sandwich panel fabrication of refractory alloys. Another report, AD–273 450P, describes the brazed alloy evaluation, manufacturing tool design, an oxidation protection coating survey, and manufacturing methods.

Further efforts in refractory technology are discussed in AD–402 713P "Joining of Refractory Metal Foils." In this work the Air Force sponsored developments on electron beam, tungsten inert gas and resistance welding on B66 alloy.

Another aspect of the exotic metals program is concerned with "Research on Tantalum and Molybdenum Brazing Techniques" as reported in AD–428 307P. Honeycomb structures for heat shield applications in the 2500° to 3500°F. temperature range are reported. For brazing titanium at temperatures less than 1100°F., two ternary basic alloys are described (AD–405 810P). Beryllium receives attention as used in composite structures (AD–278 526P and AD–282 003P). The latter presents design information plus a summary of materials and process developments for beryllium panels and heat shield ceramics.

Testing of Honeycomb Materials & Structures

The Army Engineers reported May 64 on their tests with rigid foam plastic shelters. In AD–601 179P, structural tests are described for reinforced fiberglass plastic beams and honeycomb floor panels for an experimental cold weather building. The Army Engineer R&D Labs found that bonding between the skins and core material is vital to any stressed-skin design honeycomb panel, and that fiberglass-polyester skins over polyurethane core or paper honeycomb is feasible and practical for structural use.

The Picatinny Arsenal has experimented with a lightweight aluminum honeycomb case (AD–439 657P). Aluminum core AL–3/8–3003 some 2.5-inch thick with a 1.2 lb/cu. ft. density, and skins of .012-inch clad AL–2024–T3 aluminum were evaluated by drop and hydrostatic testing.

In a series of tests reported in AD–431 513P designed to determine the energy absorption characteristics of various low-density plastic foam and aluminum honeycomb materials, the Air Force has found that aluminum honeycomb appears to present the best absorption characteristics of the low-density type materials.

For testing honeycomb structures at elevated temperatures, the Air Force has developed a thermal conductivity apparatus employing the guarded hot plate principle. While the primary objective of the instrument was honeycomb testing, a secondary objective has been concerned with the testing of

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superalloys, ceramics and cermets. The device as described in AD–421 886P was satisfactorily tested over a temperature range of 300° to 3000°F.

For the basic standards in the field, The American Society For Testing and Materials, 1916 Race Street, Philadelphia, Pa., 19103, maintains and annually upgrades the "Book of ASTM Standards." Part 16 (costing $14.00) deals with "Structural Sandwich Constructions; Wood; Adhesives" and contains 150 standards (each of which can be purchased separately) in its 180 pages. Also available direct from ASTM are: STP270, "Symposium on Durability and Weathering of Structural Sandwich Construction" (1960) and STP201, "Symposium on Structural Sandwich Construction" (1957).

RECENT BIBLIOGRAPHY AND ABSTRACTS (1962–1964)

How To Order Reports

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AD–272 096P General Dynamics, Fort Worth, Tex., SANDWICH-BRAZED TITANIUM MOLYBDENUM—CONSTRUCTION METHODS FOR—DEVELOPMENT OF, W. T. Kaarlela, Jan. 62, 20p., CFSTI $2.60.

Brazing characteristics of four high temperature brazing alloys were evaluated by brazing small tee-specimens in both argon and hydrogen atmospheres at various times and temperatures. The evaluations were based on both visual and metallurgical examinations. The use of hydrogen, as compared to argon, seemed to improve wettability and flowability in the alloys which were deficient in these characteristics. Indications are that the use of hydrogen, when compared to argon, makes possible the use of 50° to 100°F. lower brazing temperature. The report claims that 0.5% titanium molybdenum alloy holds considerable promise for use in brazed sandwich construction.

AD–273 450P Martin Marietta Corp., Baltimore, Md. MANUFACTURING METHODS AND DESIGN PROCEDURES OF BRAZED REFRACTORY METAL HONEYCOMB SANDWICH PANELS, J. W. McCown et al, Feb. 62, 94p., CFSTI $8.60.

Honeycomb sandwich panels using molybdenum and columbium core and facings can be brazed to provide lightweight structural coverings for high temperature application. The report describes panel configurations selected for fabrication that simulate hot structural and radiant heat shield applications. The special tools and procedures developed to fabricate the honeycomb cores are outlined, including electron beam welding.

AD–278 526P Aeronca Mfg. Corp., Middletown, Ohio. BERYLLIUM COMPOSITE STRUCTURES. VOL. II. MATERIALS AND PROCESSES, J. N. Krusos et al, May 62, 313p., CFSTI $5.00.

The methods developed for fabrication of Be sheet composite structures are described. Descriptions and performance evaluation are included for a variety of panels fabricated under the contract consisting of Be load bearing panels and porous ceramic heat shields developed to withstand temperatures in excess of 3000°F. Concepts are outlined defining application of Be-

ceramic composites to aerospace vehicle structures. Be sheet fabrication methods and tooling are described and include such processes as cutting, forming, chem-milling, and brazing. Be sheet faces were brazed to a variety of superalloy and stainless steel honeycomb cores. Three basic porous ceramic foams were developed in the heat shield.

AD-282 003P Aeronca Mfg. Corp., Middletown, Ohio. BERYLLIUM COMPOSITE STRUCTURES. VOL. I: DESIGN AND APPLICATION, J. N. Krusos et al, May 62, 179p., CFSTI $3.00.

Design information is presented for beryllium and ceramic composite structures. Included is a summary of materials and process developments for beryllium panels and heat-shield ceramics, analytical evaluations and discussion of the application of insulated structural concepts to re-entry vehicles. Also included in the report are the result of panel tests in the severe environments of turbojet and ramjet exhausts. Data suitable for preliminary design considerations are presented for three reinforced heat-shield ceramic foams: alumina, silica, and zirconia. Beryllium sandwich panels constructed in the course of the program are described with regard to fabrication potential and performance in aerospace structures.

AD-282 053P Rock Island Arsenal, Ill. SANDWICH DESIGN AIDS, C. M. Fitzpatrick, July 62, 50p., CFSTI $5.60.

Design aids which will simplify the analytical work for the designer of sandwich panels are presented. Included are rapid design charts for calculating the weight per sq. ft. of sandwich panels; the moment of inertia of spaced facings; and the maximum deflection of uniformly loaded, simply supported rectangular sandwich plates.

AD-282 903P Boeing Co., Seattle, Wash. CERAMIC DIELECTRIC SANDWICH COMPONENTS, D. Auda, June 62, 56p., CFSTI $6.60.

The purpose of this program was to study the feasibility of fabricating ceramic honeycomb sandwich radomes as an answer to the need for radomes which combine a high strength-to-weight ratio with resistance to extreme environments. After screening many ceramic materials and fabrication methods, slipcasting of 97% Al_2O_3 was chosen as the best means for making dense accurate parts with good unfired strength and the most satisfactory combination of fired properties. The report describes techniques which were devised for assembling and bonding slipcast parts to produce articles ready for firing. Data is given on flat sandwich specimens with longitudinally corrugated core structures tested for physical, thermal and electrical properties. Although ogive radomes constructed to determine the feasibility of fabricating large complex shapes of this structure showed some defects, the author believes that these defects could be eliminated by use of more precise tooling.

AD-285 862P Ordnance Research Labs., Penna. State Univ., University Park, Pa. SHELLS FOR UNDERWATER VEHICLES, J. D. Stachiw, Sept. 62, 56p., CFSTI $6.60.

Design criteria are discussed and basic shell designs are evaluated. Sandwich-shell designs offer the higest pressure-to-weight ratio consistent with shell design criteria. According to the report, honeycomb or microballoon fiberglass sandwich shells can be best used in the lower pressure ranges (0-1500

psi) and cellular sandwich shells for a large band of intermediate pressure ranges (1500-4000 psi). The cellular or solid sandwich shells are better used at the high pressure ranges (above 4000 psi). The report contains discussions on ring-stiffened shells, sandwich shells, internal pressurization, and an evaluation of present shell designs. The report includes a discussion of the basic methods for separating sandwich facing. These are: (1) honeycomb matrix, (2) microballoon plastic matrix, (3) cellular matrix, (4) solid filler, and (5) tubular matrix.

AD–286 490P Arthur D. Little, Inc., Cambridge, Mass. COLD-WATER SOLUBLE HONEYCOMB FACING ADHESIVE FOR FIELD USE, R. S. Lindstrom and J. J. Krackeler, Sept. 62, 72p., CFSTI $7.60.

The primary purpose of this program was to develop a dry adhesive with long storage life that could be readily dispersed in cold water in the field and used to bond the kraft facing paper to paper honeycomb core on field equipment. Formulations were tested for bond strength, ease of mixing, pot life, application characteristics and storage ability. Preliminary work was done on adhesive paste for bonding layers of faced honeycomb at temperatures to $-40°F$.

AD–291 995P Forest Products Labs., Madison, Wis. MECHANICAL PROPERTIES OF SEVERAL HONEYCOMB CORES, G. H. Stevens and E. W. Kuenzi, July 62, 9p., CFSTI $2.60.

Mechanical properties of several aluminum and reinforced plastic honeycomb cores are presented, with details of methods used to determine data. Analyzed were: relationships between compressive strength and density, compressive and shear strength, and shear properties in the two principal directions. Exploratory work was done on core materials that were either of limited production or experimental designs. Included were: commercially available honeycomb cores of aluminum alloy 5052 H39, 2024 T4 aluminum alloy cores, an aluminum core with staggered cells and cores made of ½-inch thick, heat-resistant, reinforced plastic which had 3/16-inch hexagon cells. These latter cores had a 9 pounds per cu. ft. density and were made of phenolic and silicone resins reinforced with glass fabric and asbestos mat. Properties that were evaluated included density, foil thickness, flatwise compressive strengths, compressive modulus of elasticity and shear strength.

AD–293 413P Forest Products Labs., Madison, Wis. COMPRESSIVE AND SHEAR PROPERTIES OF TWO CONFIGURATIONS OF SANDWICH CORES OF CORRUGATED FOIL, G. H. Stevens, Dec. 62, 5p., CFSTI $1.60.

Samples of honeycomb and crossbanded core were fabricated from corrugated 0.002-inch thick foil of 5052–H39 aluminum. The corrugations were ⅛-inch deep and were shaped to form either ¼-inch hexagonal cells for honeycomb core if bonded with the corrugation flutes parallel, or crossbanded core when the corrugations were laid 90° to each other. Compressive and shear properties were determined for this corrugated aluminum foil. The report finds that sandwich materials made with cores of this type and the successful application of these panels in structures requiring high strength-to-weight ratios have demonstrated their practicability.

This report is one of a series (ANC–23, Item 57–2) prepared and distributed by the Forest Products Labs.

AD–294 695P Defense Metals Information Center, Columbus, Ohio. DESIGN CONSIDERATIONS IN SELECTING MATERIALS FOR LARGE SOLID-PROPELLANT ROCKET-MOTOR CASES, C. W. Bert and W. S. Hyler, Dec. 62, 60p., CFSTI $2.00.

The intent of this document is to clarify considerations of design for the benefit of the materials specialists in the aerospace industry, and the materials industries which supply the aerospace industry. Includes discussions of: types of missiles and missile profiles; external and internal loads and environment to which missiles are subjected; stresses; structural safety and reliability from a design standpoint; materials behavior in relation to motor-case design; static mechanical behavior; fatigue behavior; thermal effects, and other environmental effects.

AD–402 713P Solar, San Diego, Calif. JOINING OF REFRACTORY METAL FOILS, Apr. 63, 481p., CFSTI $23.50.

Tests determined welding, brazing and mechanical property evaluation of refractory metal foils. Both electron beam and tungsten inert gas welding were studied along with resistance welding on the B66 alloy. Special emphasis was placed on the inert gas welding with the goal of developing parameters that would be a guide to making this a practical process. The degree of cleanliness, metal preparation, gas purification, and preheat required for successful welds in the lots of foil tested by the T16 process are listed in the report.

AD–405 810P Solar, San Diego, Calif. DEVELOPMENT OF LOW-TEMPERATURE BRAZING ALLOYS FOR TITANIUM HONEYCOMB SANDWICH MATERIALS, W. C. Troy, Jan. 62, 41p., CFSTI $1.25.

For brazing titanium under 1100°F., binary information formed the basis of selecting two promising ternary basic alloys for developments in: (1) Ag-Cu-Ge, and (2) Ag-Cu-Sn.

AD–417 415P Martin Marietta Corp., Baltimore, Md., MANUFACTURING METHODS AND DESIGN PROCEDURES OF BRAZED REFRACTORY METAL HONEYCOMB SANDWICH PANELS, J. W. McCown et al, Sept. 63, 215p., CFSTI $3.50.

This final report describes manufacturing methods and design procedures developed for fabricating details and vacuum brazing of TZM molybdenum and D–36 columbium alloy used for cores and facings of honeycomb sandwich panels. Research included the marforming of thin sheets, the welding and finishing of honeycomb core, and the high temperature vacuum brazing of panels. The capability of fabricating, coating, and utilizing brazed columbium sandwich panels on aerospace vehicles at temperatures up to 2400°F. was demonstrated. Only partial success was achieved with the TZM molybdenum alloy because of welding problems encountered in edge sealing of the panels.

AD–421 886P Dynatech Corp., Cambridge, Mass. AN INSTRUMENT FOR MEASURING THE THERMAL CONDUCTANCE OF HIGH-TEMPERATURE STRUCTURAL MATERIALS, J. K. Sparrell et al, Sept. 63, 52p., CFSTI $1.50.

A thermal conductivity apparatus employing the absolute guarded hot plate

principle was designed, developed and fabricated. The primary objective of this instrument is to test honeycomb structures at elevated temperatures. A secondary objective is to test superalloys, ceramics, and cermets. Operational requirements included temperatures of 300° to 3000°F. Thermal conductivity tests were made on an assortment of materials. A detailed discussion of instrumentation and materials compatibility problems encountered during the program is included.

AD–428 307P Northrop Corp., Hawthorne, Calif. RESEARCH ON TANTALUM AND MOLYBDENUM BRAZING TECHNIQUES, A. H. Freedman and E. B. Mikus, Oct. 63, 35p., CFSTI $2.60.

These tests aim at developing brazing systems for the above materials for use in honeycomb structures for heat-shield applications in the range of 2500° to 3500°F.

A literature survey was conducted which indicated that: (1) no completely satisfactory conventional or high remelt temperature braze systems have been developed for molybdenum and tantalum, (2) the diffusion sink and reactive brazing concepts offer the most potential for increasing joint remelt temperatures, (3) titanium-base alloys offer the most promise for molybdenum and tantalum diffusion sink braze alloys, and (4) columbium-based alloys offer the most promise for conventional brazing of tantalum.

AD–430 258P General Dynamics, Fort Worth, Tex., FACE WRINKLING AS A FUNCTION OF SURFACE WAVINESS, C. W. Rogers, May 63, 25p., CFSTI $2.60.

This report attempts to establish the correlation between surface waviness of honeycomb panels and the face wrinkling resulting when subjected to compressive forces. Tests were conducted on edgewise compression specimens.

AD–431 513P McDonnell Aircraft Corp., St. Louis, Mo. DETERMINATION OF THE ENERGY ABSORPTION CHARACTERISTICS OF VARIOUS LOW-DENSITY FOAM TYPE PLASTICS, J. Swafford, Mar. 64, 37p., CFSTI $3.60.

Describes efforts made to determine the energy absorption characteristics of various low-density plastic foam and aluminum honeycomb materials. Based on the results of this test program, aluminum honeycomb appears to present the best absorption characteristics of the low-density type materials tested.

AD–431 932P Don Bosco Inst. for Research, Ramsey, N.J. THE VIBRATION OF A SANDWICH PLATE WITH INTERNAL DAMPING, RADIATING INTO A FLUID MEDIUM ON ONE SIDE, S. W. Jones and V. L. Salerno, Jan. 64, 49p., CFSTI $4.60.

Numerical readings are given for a lightly damped (conventional honeycomb) sandwich plate and a highly damped (rubberized dissipative) core plate; also a calculation procedure to facilitate use of the theory on practical problems. A theory is developed for the vibration analysis of an infinitely long sandwich plate whose facings and core have linear damping properties.

AD-432 259P Forest Products Labs, Madison, Wis. SHORT-COLUMN COMPRESSIVE STRENGTH OF SANDWICH CONSTRUCTION AS AFFECTED BY SIZE OF CELLS OF HONEYCOMB CORE MATERIALS, C. B. Norris, Jan. 64, 15p., CFSTI $1.60.

To determine the effect of honeycomb core cell size on edgewise compression of sandwich constructions, sandwich specimens were evaluated that had aluminum facings of various thicknesses and a solid core of Sitka spruce in which a cell of a honeycomb core material was simulated. Tests involving honeycomb cores were made and results were found to agree with those of other tests for the stress at the start of dimplings of the facings. The maximum stress in the facings of the honeycomb core specimens was lower at failure than for the specimens with wood cores.
An empirical formula was obtained for estimating critical stresses at which failures will occur in honeycomb sandwich structures.

AD-439 657P Hexcel Products Co., Berkeley, Calif. DEVELOPMENT AND EVALUATION OF A LIGHTWEIGHT ALUMINUM HONEYCOMB CASE, M. N. Bandak, Apr. 64, 42p., CFSTI $4.60.

Fabrication and testing of typical construction specimens and a prototype case are described. Tests of typical construction were accomplished by use of a drop test for specimens with constant and varying loaded area. Hydrostatic pressure test results and a summary of drop-test results for various core materials and thicknesses are included.

AD-600 869P Forest Products Labs., Madison, Wis. PERFORMANCE OF SANDWICH PANELS IN FPL EXPERIMENTAL UNIT, L. O. Anderson and L. W. Wood, May 64, 41p., CFSTI $1.25, MF 50 cents.

Design and construction details of the experimental unit are described. This unit provided a facility for longtime exposure tests of various types of sandwich wall panels under conditions simulating those of dwellings. The performance of individual panels after long periods of exposure are discussed.

AD-601 179P Army Engineer Research and Development Labs., Fort Belvoir, Va. RIGID FOAM PLASTIC SHELTERS. STRUCTURAL TESTS OF REINFORCED FIBERGLASS PLASTIC BEAMS, HONEYCOMB FLOOR PANELS, AND EXPERIMENTAL GREENLAND BUILDING, R. K. Hendrick and A. Perez, May 64, 66p., CFSTI $1.75, MF 75 cents.

The report covers structural tests to evaluate rigid foam plastic shelters. The report concludes: (1) It is feasible to fabricate structural members by using fiberglass-polyester skins over either polyurethane core or paper honeycomb core, and (2) bonding between the skins and the core material is of utmost importance in stressed-skin design.

AD-602 068P Payne (Charles) and Assoc., Miami, Fla. APPLICATION OF THE INTERACTING LAMINAR SHELL CONCEPT TO ANTENNAS AND OTHER GROUND ELECTRONIC SYSTEM SUPPORT STRUCTURES, C. Payne et al, July 62, 287p., CFSTI $4.00, MF $1.50.

This document provides the results of experimental stress analysis on a model of an interacting laminar shell antenna structure; it develops influence diagrams for design use, and gives preliminary designs for eight different antennas.

Interacting laminar shell construction is an arrangement of structural shells (laminar structural surfaces) permitting optimum utilization of high strength materials of thin cross section by inherent stabilization characteristics of the system. The report describes the shell system as inherently panelized, permitting factory fabrication by production techniques. Universal adjustment of the relative panel positions is possible even under full structural loading by precise regulation of surface curvature, maintained by an electronic control system.

AD–604 685P Boeing Co., Seattle, Wash. METAL-CERAMIC STRUCTURAL COMPOSITE MATERIALS, J. W. Vogan and J. L. Trumbull, Feb. 62, 185p., CFSTI $5.00, MF $1.00.

Thoria and magnesia bodies were developed for use in metal ceramic composites. Plasma and oxyacetylene torch tests developed to evaluate these materials and similar zirconia composites showed that magnesia and zirconia can be used to 4700°F. and thoria to 5400°F. Platinum and Inconel honeycomb were selected for use as a metal reinforcement.

AD–607 088P Martin Marietta Corp., Orlando, Fla. THERMAL RESPONSE IN SANDWICH PANELS, P. J. Kendall, Oct. 64, 192p., CFSTI $5.00, MF $1.00.

A system of equations for predicting thermal responses in a variety of sandwich panels is programmed for solution on the IBM 7094 digital computer. An analytical model is presented for predicting thermal response in honeycomb sandwich panels. The model considers a variety of configurations involving single or stacked panels. The heat balance equations given are of the finite difference form and employ the forward difference technique for solution. Validity of a portion of the analytical model is established by comparing predicted results to existing experimental data for single honeycomb panels.

AD–607 339P Oklahoma Univ. Research Inst., Norman, Okla. RESEARCH IN THE FIELD OF FIBERGLASS REINFORCED SANDWICH STRUCTURE FOR AIRFRAME USE, G. Nordby et al, July 64, 144p., CFSTI $4.00, MF $1.00.

This is a study to determine strength properties of reinforced plastic sandwich structures for use as primary airframe structural material. The program scope covered the determination of the effect of curing time, pressure, and temperature, as well as lay-up methods on the basic strength properties of the sandwich. Program results include the isolation of the optimum conditions of fabrication, the expected strength values for these optimum fabrication conditions, and the performance of several adhesive system-core material combinations. Among the byproducts of the program is a multi-ply coating machine that is capable of impregnating several layers of fabric simultaneously.

EARLIER BIBLIOGRAPHY
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AD–271 166P Boeing Co., Wichita, Kansas. BOEING-WICHITA MATERIALS AND RESEARCH DEVELOPMENT PROGRAMS 1957-1961, INCLUDES SANDWICH CONSTRUCTION, A. H. Poe and H. E. Shigley, June 61, 136p., CFSTI $10.50.

AD–272 016P Minnesota Univ., Minneapolis. DAMPING AND FATIGUE PROPERTIES OF SANDWICH CONFIGURATIONS IN FLEXURE, L. Keer and B. J. Lazan, Nov. 61, 60p., CFSTI $1.75.

AD–276 008P General Dynamics, Fort Worth, Tex. DEVELOPMENT OF BRAZED BERYLLIUM SANDWICH CONSTRUCTION, S. V. Glorioso et al, Dec. 60, 27p., CFSTI $1.00.

AD–297 506P Southhampton Univ., Gt. Brit. THE DAMPING OF ALUMINUM HONEYCOMB SANDWICH BEAMS, D. J. Mead and G. R. Froud, No. 61, 24p., CFSTI 75 cents.

PB–165 066P California Univ., Los Angeles, Calif. THERMAL STUDIES OF HONEYCOMB SANDWICH STRUCTURES EXPOSED TO TRANSIENT EXTERNAL HIGH-INTRACELLI RADIATION, T. Ishimoto and H. Kaysen, Jan. 58, 110p., CFSTI $9.10.

PB–166 173P Columbia Univ., New York, FLEXURAL VIBRATIONS OF ELASTIC SANDWICH PLATES, R. D. Mindlin, Aug. 59, 16p., CFSTI $1.00, MF 50 cents.

PB–171 168P Forest Products Labs., Madison, Wis. MOLDED COMPOSITE FOR BOAT HULLS, SANDWICH PANELS—TEST RESULTS, B. G. Heebink et al, June 60, 43p., CFSTI $1.25.

PB–171 408P Ohio State Univ., Research Foundation, Columbus, Ohio. EVALUATION OF BRAZED HONEYCOMB STRUCTURES, R. C. McMaster et al, Sept. 60, 321p., CFSTI $5.00.

PB–181 042P Williams, Clyde and Co., Columbus, Ohio. CELLULAR METAL. AN INTRIGUING MATERIALS CONCEPT, 1961, 22p., CFSTI 50 cents.

AD–275 280P Lockheed Aircraft Corp., Sunnydale, Calif. ALL-METAL SANDWICHES EXCEPT HONEYCOMB-CORE. AN ANNOTATED BIBLIOGRAPHY, E. E. Graziano, Mar. 62, 78p., CFSTI $8.10.

AD–276 962P Watertown Arsenal R&D Div., Mass. A BIBLIOGRAPHY OF REPORTS OF SANDWICH CONSTRUCTION FOR ORDNANCE DESIGN ENGINEERS, M. H. Matizian, Apr. 62, 12p., CFSTI 50 cents.

AD–282 465P North American Aviation Inc., Downey, Calif. CERAMIC FOAM AND CERAMIC HONEYCOMB: A LITERATURE SURVEY, Feb. 62, 8p., CFSTI $1.60.

AD–298 717P Douglas Aircraft Co., Inc., Santa Monica, Calif. FOR THE SPACE AGE. A BIBLIOGRAPHY OF SANDWICH PLATES AND SHELLS, J. I. Foss, Dec. 62, 98p., CFSTI $2.50.

Comprises 838 items on theoretical and experimental stress analysis of sandwich constructions (plates and shells). Core-to-face attachments, design applications, fabrication methods, mechanical properties, testing procedures and inspection methods are included. Subject and author cross referred. Covers 1952-1962.

SB–517 CFSTI SELECTIVE BIBLIOGRAPHY PRICE LIST ON SANDWICH CONSTRUCTION, Sept. 63, CFSTI no charge.

A bibliography of reports listed in the CFSTI collection.

A valuable source of sandwich and laminated materials research is the U.S. Department of Agriculture's Forest Service Forest Products Laboratory at Madison, Wisconsin. Operating in conjunction with the Univ. of Wisconsin, it publishes a "LIST OF PUBLICATIONS ON STRUCTURAL SANDWICH, PLASTIC, LAMINATES, AND WOOD-BASE COMPONENTS." This May 64 publication, available directly from the Forest Products Laboratory, Madison, Wisconsin, references 83 reports dealing primarily with sandwich materials of wood and plastic over the period 1944-1964.

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